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PREDICTION OF BODY COOLING

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August 1997

DCIEM No. 97-TM-47

PREDICTION OF BODY COOLING

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EXECUTIVE SUMMARY

The prediction of survival time for cold water immersion is very difficult due to several uncertainties. Foremost is the lack of well-documented data; hence the reliance of extrapolative techniques from controlled exposures involving mild levels of hypothermia. A second obstacle is the wide variability of individual response to cold. The challenge of prediction is further exacerbated by the ambiguity in the definition of survival time. These concerns must be addressed to improve the safety and rescue of people in the offshore environment.

An international workshop was held to investigate the role of survival prediction models with a special emphasis on terminology. Following a review of prediction methods and models, assumptions were discussed, standard definitions were agreed upon, the extension to specific populations was noted, a standard clothing menu for modeling purposes was agreed upon, the collation of case histories and their use for model calibration and validation was discussed, and future directions were summarized. The primary recommendation was the adoption of the definition of survival time as the time for a body to cool to 28°C. This definition purposely excludes the possibility of death by factors other than hypothermia such as drowning. In addition, the workshop group agreed upon a new term to signify the impairment in motor and cognitive abilities associated with a body temperature of 34°C. The time to cool to this point was termed the 'Functional' time. It can be assumed that individuals are capable of self-help up to this point. It is further recommended that this definition be applied as a threshold criterion in the design of protective garments and in the standardization of offshore safety policy.

The workshop also recognized the importance of a recent comprehensive immersion survey in the UK that provides the probability of being found alive as a function of water temperature, immersion time, and buoyancy device. This differs from the hypothermia-based models referred to above since all life-threatening possibilities are included. The value of such probabilities is the estimation of the number of survivors when large numbers of casualties are involved. It is suggested that the integration of this probability function into a body cooling model would result in a meaningful decision aid for search and rescue operators and the offshore safety community.

1. Background. Human exposure to cold evokes physiological responses that primarily involve changes in blood circulation (e.g., vasoconstriction) and metabolic heat production (e.g., shivering). The characterization of these responses has been the subject of considerable research over the past few decades and is closely followed by the development of mathematical models to predict these responses. The result is a collection of models that perform well in the domain of conditions used to calibrate the model. However, this domain is usually restricted to mild degrees of hypo or hyperthermia for ethical reasons. Predictions beyond this domain involve extrapolative procedures. This is a special concern for models used to predict the survival time of individuals immersed in cold water. The terminology and validation of these model predictions is the subject of the workshop that is reported herein.

The workshop was not intended to choose which model is most appropriate for the prediction of survival time, but to establish the role of such models. Foremost, what is the most appropriate output of the model? To address this, it is necessary to understand who the user is. The Search and Rescue (SAR) community requires rational estimates of survival time so that informed decisions can be made regarding the allocation of personnel and resources, and on the termination of a search. To the agencies responsible for the safety of the offshore worker, a prescriptive application of a survival prediction model would aid decisions on setting minimal levels of personal protection. Neither of these groups are interested in the intricacies of the prediction model; instead, their concerns lie with the ease of the model's use and its validity.

This report summarizes the findings of the workshop group (Annex A lists the participants of the group). Several topics were discussed and are presented below. In some cases, topics were combined for continuity. While a consensus was attained on many points, these findings reflect the opinion of several experts and are not to be construed as policy of the nations represented. Nevertheless, it is felt that agencies tasked with offshore safety and standardizations should consider these findings seriously, and if adopted, this should help resolve some of the ambiguity in the present terminology of survival limits for cold water immersion.

2. Review of Prediction Methods/Models. A review of the literature reveals several methods and models available for predicting survival time (see Annex B). In some cases, these predictions refer to the time of death; in others, they refer to specific deep body temperatures corresponding to various degrees of incapacitation. A simple plot of these survival times against water temperature is shown in Annex C. It is evident that all these predictions agree very closely for extreme cold water conditions (i.e., < 5°C), but a marked divergence begins as water temperature increases. It is also noteworthy that the predictions based on Molnar (1946), Veghte (1972), and Oakley (1997) do not distinguish deaths due to drowning from those due to hypothermia. The remaining predictions are exclusively based on hypothermia. Some of the disparities seen in the figure in Annex C can be attributed to differences in individual characteristics and clothing protection.

If the intention is to predict survival time for cold water immersion without regard to how death occurs, then the statistically-based model of Oakley (1997) is perhaps the most comprehensive choice presently available. It makes a clear separation of survival probabilities for individuals donned with or without a buoyancy device. If, on the other hand, a prediction of survival time pertaining only to hypothermia is required, then a thermally-based model of body cooling should be used. This is certainly the case for the prescriptive mode, e.g., where an estimation of immersion suit performance is required.

3. Critical Evaluation of Model Assumptions. The prediction of body cooling is relatively straightforward provided that heat production and heat loss are properly accounted. This assumes that the underlying physiological response to cold and the physical processes of heat exchange

are known. In the circumstance where an individual's rate of heat loss exceeds his/her maximal heat production, that individual will experience a continuous loss of body heat and an unchecked decline in deep body temperature (T_{core}). Models can be tested on their predictive performance on the initial stages of body cooling from experimental data.

The more challenging circumstance arises when the cold-exposed individual is able to balance his/her heat loss with heat production. This introduces the uncertainty of how long the individual can maintain an elevated level of heat production. If the individual is stationary, the only source of internal heat production in addition to resting metabolism is through shivering. At present, shivering endurance has not been rigorously measured and remains as one of the primary uncertainties in the model prediction of survival time. Shivering endurance can, however, be estimated using an approximation proposed by Wissler (1985). Testing the accuracy of the resultant model prediction of survival time necessitates the use of case histories which introduces additional complications as outlined further below.

4. Standardized Definitions and Presentation of Predictions. There is a wide range of definitions of survival time for cold water immersion used across the industry and found in the literature, often leading to some confusion. After lengthy discussions on this point, the consensus of the workshop group was that a working definition of survival time (hereafter referred to as ST) be based on a T_{core} of 28°C. While no specific reference defines this temperature as the population average for lethal hypothermia, the group agreed that this is certainly closer to representing a 50% probability of death due to hypothermia than a deep body temperature of < 27°C or > 29°C. It is also important to note that the proposed definition purposely excludes the possibility of death due to drowning.

The above definition has applicability for the SAR community where an "optimistic" prediction is warranted. For the prescriptive application of a body cooling model, it would be extremely useful to provide a prediction of the individual's functional time (FT). This represents the point when the individual's cognitive and motor functions become impaired, and self-help is limited. The group's consensus on the T_{core} representing this state is 34°C. Ignoring the possibility of death due to drowning or other untoward events, individuals are expected to completely survive the "hypothermia" associated with deep body cooling to this temperature. It is therefore recommended that protection for cold water immersion be guided by the FT and not ST.

5 Extension of Model Predictions to Specific Populations. Model predictions are almost exclusively based on the response of young Caucasian males to cold exposure largely due to the abundance of cold exposure data for this sub-population. It is usually assumed that differences in thermoregulatory response to cold of other sub-populations can simply be attributed to differences in individual characteristics. There is a limited number of studies on the female response to cold (McArdle et al 1984; Wagner and Horvath 1985; Mannino and Kaufman 1986; Graham et al 1989) and it is recommended that these be reviewed by modellers to assure that current model predictions are not grossly under or overestimating this response. With regard to variations in cold response due to age, race, and other personal attributes, there presently are insufficient data for modelling purposes.

6. Creation of a Standardized Clothing Menu. The predictions of FT and ST are sensitive to the amount of clothing protection worn by the individual. In this regard, it was felt that a consensus on the level of protection for various clothing would be helpful. Rather than assign the level of *in situ* insulation to specific garments, the workshop group agreed on the following assignment of insulation values to the generic classification of clothing listed in the UK National Immersion Incident Survey Questionnaire (Oakley and Pethybridge 1997):

minimal (essentially nude)	0 clo
light clothing (casual/fair weather wear)	< 0.05 clo
heavy clothing (bulky/cold weather wear thoroughly soaked)	0.05 - 0.2 clo
dry suit (uninsulated with underclothing)	0.3 - 0.5 clo
and wet suit (immersed)	0.3 - 0.5 clo.

7. Standardization and Collation of Case Histories. It is clear from the preceding that data are limited for testing model predictions. While laboratory results can and should be used to test the prediction of FT, controlled data are too controversial (Alexander 1945) to test the prediction of ST. Hence the requirement for well-documented cases of survival and death due to hypothermia. Unfortunately, while there is an abundance of cold water immersion incidents, there are very few cases that have been sufficiently documented for testing purposes. The workshop group identified the following exceptions. The UK National Immersion Incident Survey (Oakley and Pethybridge 1997) provides a reasonably detailed summary of 900 immersion incidents involving 834 survivors. Information on the victims' build, clothing worn, sea conditions, and immersion times are given. The data on fatalities include drownings and cannot be used to test body cooling predictions. However, predictions on the body cooling rates of survivors might be testable, as outlined further below.

Another potential source of information involves a recent capsizing of a Norwegian fishing vessel (Pasche; private communication). Nine men donned immersion suits before entering the water although not all suits remained dry. Air and water temperatures were ~ -8 and 2°C, respectively, and it was windy with choppy seas. At the time of rescue after 5.5 h of immersion, three men were dead and of the remaining six, five men showed no signs of shivering. One of the surviving men had a T_{core} of 31°C which is consistent with the cessation of shivering observed for deep hypothermia.

Other case histories that are worthy of further investigation include the Lakonia incident involving long-term immersions in moderately cold water (Keatinge 1965), the Estonia ferry incident involving very cold and turbulent sea conditions, and the ditching of a transport helicopter in the North Sea (AAIB 1993).

8. Calibration and Validation of Model Predictions. As stated earlier, the testing of model predictions of FT is not problematic since ample data are available from controlled laboratory experiments. Testing the prediction of ST is entirely different and reliant on well-documented case histories. One possibility of utilizing the UK National Immersion Survey is to compare predictions and observations by category. For example, the survey describes the condition of the survivors at the time of rescue as either well, drowsy, or unconscious. If the predictions of the model can be categorized in these terms, then a non-parametric statistical goodness of fit can be conducted to calibrate the model and subsequently to test the model as new data become available. A consensus was reached on the following T_{core} ranges pertaining to the survivor status:

well	> 35°C
drowsy	32 - 35°C
unconscious	< 32°C.

9. Recommendations and Future Directions. The following is proposed for predicting survival outcome for cold water immersion. First, the predictions of FT and ST can be obtained from a thermally-based model of body cooling. Second, the prediction of the probability of survival for various times up to ST can be obtained using the UK model (Oakley and Pethybridge 1997). For example, the values of FT and ST for a lightly dressed average individual

immersed in 10°C calm water are 2.6 and 4.2 h, respectively (Tikuisis 1997). According to the UK model, the probabilities of surviving until the FT (i.e., 2.6 h) are 91 and 67% with and without buoyancy, respectively. The latter values can be quite informative for incidents involving several individuals. For example, if 30 people were involved in the above situation, then 20 to 27 can be expected to be alive after 2.6 h of immersion.

A primary recommendation from the workshop group is the definitions of FT and ST. FT (functional time) is defined as the time taken for the deep body to reach a temperature of 34°C which signifies a degree of incapacitation (both cognitive and motor) sufficient to limit self-help. This threshold should govern the design of protective garments and standardizations of offshore safety. ST (survival time) is defined as the time taken to reach 28°C which is close to the average deep body temperature when the cause of death is hypothermia.

The key to obtaining accurate predictions of survival outcome is a sufficiently large database of well-documented case histories that can be used to calibrate and validate models. Efforts must be channeled to establish such a database using the UK example. There are numerous assumptions inherent in the prediction models that must also be verified. The greatest uncertainty at present is shivering endurance. Fundamental research in this direction would contribute significantly to the prediction of ST.

10. Acknowledgements. This workshop, under the subtitle "Development of a Computer Model to Predict Survival Time in Cold Water for Particular Application in the Offshore Oil Industry," was financially supported by the Energy Resources Branch of the Department of Natural Resources Canada. We are also in debt to the Centre of Human Studies of the Defence Enhancement Research Agency Farnborough, UK for very graciously providing excellent facilities in hosting this meeting.

Submitted by:

Peter Tikuisis, Ph.D.

Approved by:

Ira Jacobs, Dr. Med. Sc.

Annex A: - Workshop Location, Date, and Participants

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DERA Centre for Human Sciences
Farnborough, Hampshire
14-16 Jul 1997

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Annex B

Selected Literature Survey of Cold Water Immersion Hypothermia and Survival

Prediction models:

Hall JF (1972). Prediction of tolerance in cold water and life raft exposures. Aerospace Med 43(3):281-286.

Hayes PA et al. (1988). The calculation of survival time in cold water using a hand-held computer. IAM Report No. 568, Farnborough, UK.

Hayward JS et al. (1974). Thermal balance and survival time prediction of man in cold water. Can J Physiol Pharmacol 53:21-32.

Hayward JS et al (1977). Thermoregulatory heat production in man: prediction equation based on skin and core temperatures. J Appl Physiol 42(3):377-384.

Hayward JS and Eckerson JD (1984). Physiological responses and survival time prediction for humans in ice-water. Aviat Space Environ Med 55(3):206-212.

Nunneley SA et al. (1985). Immersion cooling: effect of clothing and skinfold thickness. Aviat Space Environ Med 56:1177-1182.

Oakley EHN and Pethybridge RJ (1997). The prediction of survival during cold immersion: results from the UK national immersion incident survey. INM Report No. 97011, Alverstoke, UK.

Roberston DH and Simpson ME (1996). Review of probable survival times for immersion in the North Sea. Offshore Tech Report - OTO 95 038, MaTSU, Abington, UK.

Shender BS et al (1995). Cold water immersion simulations using the Wissler Texas thermal model: validation and sensitivity analysis. Aviat Space Environ Med 66:678-686.

Sowood PJ et al. (1987). Validation of mathematical model predictions of immersion survival times. IAM Report No. 652, Farnborough, UK.

Steinman AM and Hayward JS (1995). Cold water immersion. In: Wilderness Medicine, Averbach PS (ed). Mosby, St. Louis, USA, 104-128.

Tikuisis P et al (1988). Thermoregulatory model for immersion of humans in cold water. J Appl Physiol 64:719-727.

Tikuisis P et al (1988). Prediction of human thermoregulatory responses and endurance time in water at 20 and 24°C. Aviat Space Environ Med 59:742-748.
Tikuisis P (1995). Predicting survival time for cold exposure. Int J Biometeorol 39:94-102.

Tikuisis P (1997). Prediction of survival time at sea based on observed body cooling rates. Aviat Space Environ Med 68(5):441-448.

Wissler EH (1985). Mathematical simulation of human thermal behaviour using whole- body models. In: Shitzer A, Eberhart RC (eds). Heat transfer in medicine and biology, v1, Plenum Press, New York, pp 347-355.

Timbal J et al (1976). Mathematical model of man's tolerance to cold using morphological factors. Aviat Space Environ Med 47:958-964.

Wissler EH (1984). An evaluation of human thermal models. Workshop Report, Univ. Texas at Austin.

Wissler EH (1985). Mathematical simulation of human thermal behaviour using whole-body models. In: Shitzer A, Eberhart RC (eds). Heat transfer in medicine and biology, v 1, Plenum Press, New York, pp 347-355.

Physiological responses:

Alexander L (1945). The treatment of shock from prolonged exposure to cold, especially in water. Office of the Publication Board Report No. 250, Dept Commerce, Washington, D.C.

Bell DG et al (1992). Relative intensity of muscular contraction during shivering. J Appl Physiol 72(6):2336-2342.

Boutelier C (1979). Survival and protection of aircrew in the event of accidental immersion in cold water. NATO AGARDogragh No. 211, Hartford House, London, UK.

Behnke AR and Yaglou CP (1950). Physiological responses of men to chilling in ice water and to slow and fast rewarming. J Appl Physiol 3:591-602.

Collis ML (1983). Survival behaviour in cold water immersion. Swim Teacher 12:17-20.

Cooper KE et al (1976). Respiratory and other responses in subjects immersed in cold water. J Appl Physiol 40(6):903-910.

Cannon P and Ketainge WR (1960). The metabolic rate and heat loss of fat and thin men in heat balance in cold and warm water. J Physiol 154:329-344.

Currie J (1798). Effects of water, cold and warm. Med Report, M'Creery, London, UK.

Graham TE et al (1989). Thermal and metabolic responses to cold by men and by eumenorrheic and amenorrheic women. J Appl Physiol 67(1):282-290.

Golden FStC (1976). Hypothermia: a problem for North Sea industries. J Soc Occup Med 26:85-88.

Goode RC et al (1975). Sudden cold water immersion. Resp Physiol 23:301-310.

Gooden BA (1992). Why some people do not drown. Med J Aust 157:629-632.

Hayward JS et al. (1975). Effect of behavioral variables on cooling rate of man in cold water. J Appl Physiol 38(6):1073-1077.

Iampietro PF et al (1960). Heat production from shivering. J Appl Physiol 15(4):632-634.

Jacobs I et al (1984). Effects of endurance fitness on responses to cold water immersion. Aviat Space Environ Med 55:715-720.

Keatinge WR and Evans M (1961). The respiratory and cardiovascular response to immersion in cold and warm water. Qtly J Exptl Physiol 46:83-94.

Keatinge WR et al (1964). Cardiovascular responses to ice-cold showers. J Appl Physiol 19(6):1145-1150.

Keatinge Wrand Nadel JA (1965). Immediate respiratory response to sudden cooling of the skin. J Appl Physiol 20(1):65-69.

Keatinge WR et al (1969). Sudden failure of swimming in cold water. Brit Med J 1:480-483.

Keatinge WR (1972). Cold immersion and swimming. J Royal Naval Med Service 58:171-176.

Keatinge WR (1977). Accidental immersion hypothermia and drowning. Practitioner 219:183-187.

Keatinge WR (1984). Hypothermia at sea. Med Sci Law 24(3):160-162.

Mannino JA and Kaufman MS (1986). Comparative cold responses of men and women to external and internal stimuli. Aviat Space Environ Med 57:27-30.

McArdle WD et al (1984). Thermal adjustment to cold-water exposure in resting men and women. J Appl Physiol 56(6):1565-1571.

McArdle WD et al (1984). Thermal adjustment to cold-water exposure in exercising men and women. J Appl Physiol 56(6):1572-1577.

Mekjavic IB et al (1987). Respiratory drive during sudden cold water immersion. Resp Physiol 70:121-130.

Sarnaik AP and Vohra MP (1986). Near-drowning: fresh, salt, and cold water immersion. Clinics Sports Med 5(1):33-46.

Sterba JA (1990). Arctic cold weather medicine and accidental hypothermia. NEDU Report No. 2-90, US Navy, Panama City, FL, USA.

Strong LH (1985). Metabolic and vasomotor insulative responses occurring on immersion on cold water. J Appl Physiol 58(3):964-977.

Tikuisis P et al (1988). Role of body fat in the prediction of the metabolic response for immersion in cold water. Undersea Biomed Res 15:123-134.

Tikuisis P et al (1991). Shivering onset, metabolic response, and convective heat transfer during cold air exposure. J Appl Physiol 70(5):1996-2002.

Tipton MJ (1989). The initial responses to cold-water immersion in man. Clin Sci 77:581-588.

Tipton MJ et al (1991). Human initial responses to immersion in cold water at three temperatures and after hyperventilation. J Appl Physiol 70(1):317-322.

Toner MM et al (1985). Thermal responses during arm and leg and combined arm-leg exercise in water. J Appl Physiol 56(5):1355-1360.

Toner MM et al (1985). Comparison of thermal responses between rest and leg exercise in water. J Appl Physiol 59(1):248-253.

Toner MM et al (1985). Effects of body mass and morphology on thermal responses in water. J Appl Physiol 60(2):521-525.

Wagner JA and Horvath SM (1985). Influences of age and gender on human thermoregulatory responses to cold exposures. J Appl Physiol 58(1):180-186.

Case histories:

Air Accidents Investigation Branch (1993). Report on the accident to AS 332L Super Puma, G-TIGH near the Cormorant 'A' platform, East Shetland Basin, on 14 March 1992. Aircraft Accident Report 2/93, Dept Transport, HMSO London.

Keatinge WR et al (1986). Exceptional case of survival in cold water. Brit Med J 292:171-172.

McCallum AL et al (1989). Two cases of accidental immersion hypothermia with different outcomes under identical conditions. Aviat Space Environ Med 60:162-165.

McCance RA et al. (1956). The hazards to men in ships lost at sea, 1940-44. Med Res Council Report No. 291, London, UK.

Molnar GW (1946). Survival of hypothermia by men immersed in the ocean. J Am Med Assoc 131:1046-1050.

Talbot AG et al. (1946). Report of naval life saving committee. IAM, Alverstoke, UK.

Veghte JH (1972). Cold sea survival. Aerospace Med 43(5):506-511.

Protective clothing:

Allan JR et al (1982). Measurements of survival clothing insulation using an immersed manikin. IAM Report No. 475, Farnborough, UK.

Allan JR et al (1985). The effect of leakage on the insulation provided by immersion-protection clothing. Aviat Space Environ Med 56:1107-1109.

Ducharme MB and Brooks CJ (1996). The effects of wave conditions on dry immersion suit insulation. DCIEM Report No. 96-R-46, North York, Ontario, Canada.

Hayes P (1986). Physiological aspects of survival clothing. Paper No. 28 at Intl Conf on Escape, Survival, Rescue at Sea, London, UK.

Hayward JS et al. (1972). Survival suits for accidental immersion in cold water. Univ. Victoria Report, British Columbia, Canada.

Hayward JS (1984). Thermal protection performance of survival suits in ice-water. Aviat Space Environ Med 55(3):212-215.

Keatinge WR (1961). The effect of work and clothing on the maintenance of the body temperature in water. Qtly J Exptl Physiol Cognate Med Sci 46:69-82.

Keatinge WR (1965) Death after shipwreck. Lancet 2:1537-1541.

Romet TT et al. (1991). Immersed clo insulation in marine work suits using human and thermal manikin data. Aviat Space Environ Med 62:739-746.

Steinman AM and Kubilis PS (1986). Survival at sea: the effects of protective clothing and survivor location on core and skin temperatures. Coast Guard Report No. CG-D-26-86, Washington, DC, USA.

Steinman AM et al. (1987). Immersion hypothermia: comparative protection of anti-exposure garments in calm versus rough seas. Aviat Space Environ Med 58:550-558.

Tanaka M (1978). Metabolic and thermal responses of men wearing cold-protective clothing to various degrees of cold stress. Eur J Appl Physiol 39:137-144.

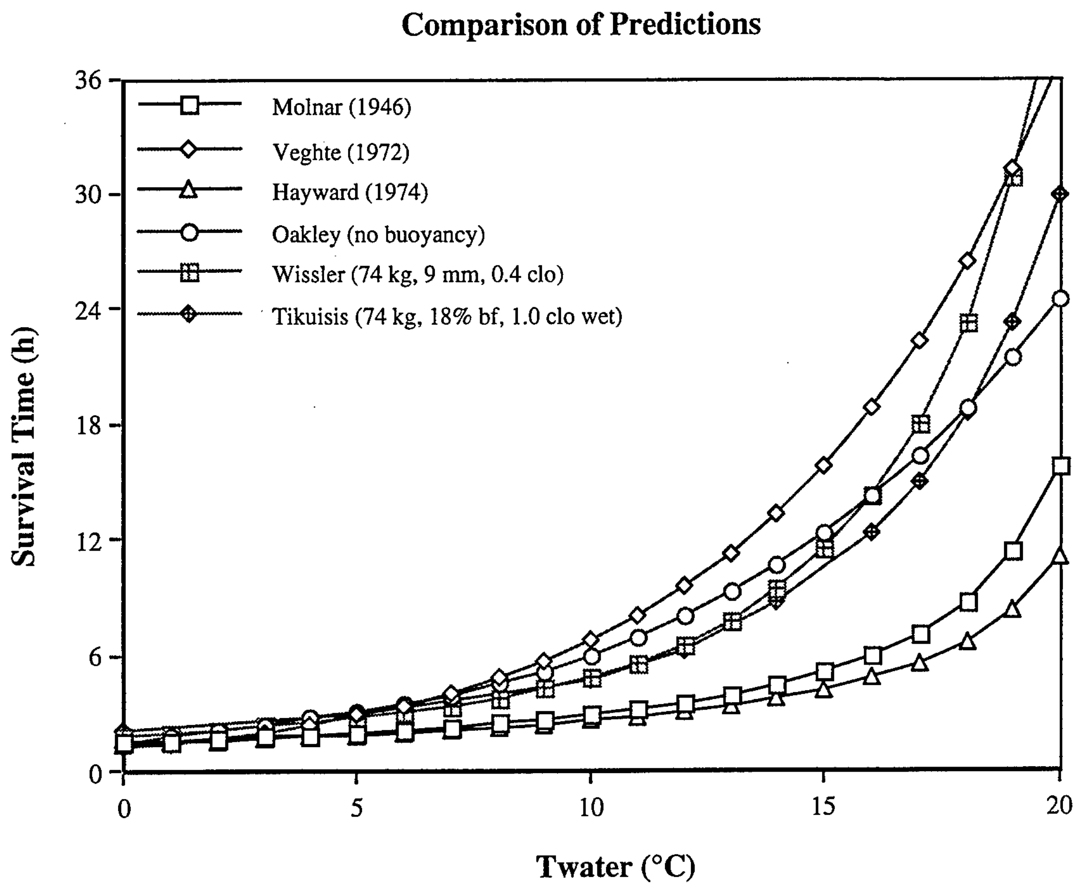
Tikuisis P (1989). Prediction of thermoregulatory response for clothed immersion in cold water. Eur J Appl Physiol 59:334-341.

Tipton MJ and Golden FStC (1987). The influence of regional insulation on the initial responses to cold immersion. Aviat Space Environ Med 58:1192-1196.

Tipton MJ and Balmi PJ (1996). The effect of water leakage on the results obtained from human and thermal manikin tests of immersion protective clothing. Eur J Appl Physiol 72:394-400.

Annex C

Comparison of Predictions of Survival Time



<u>Figure References</u>:

Hayward (Hayward et al. 1974)
Oakley (Oakley EHN and Pethybridge RJ 1997)
Wissler (Hayes et al. 1988)
Tikuisis (Tikuisis 1997)

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g., Establishment sponsoring a contractor's report, or tasking agency, are entered in section 12.) Defence and Civil Institute of Environmental Medicine 1133 Sheppard Avenue West, North York, Ontario, Canada, M3M 3B9	2. DOCUMENT SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable) UNCLASSIFIED

3. DOCUMENT TITLE (the complete document title as indicated on the title page. Its classification should be indicated be the appropriate abbreviation (S,C,R or U) in parentheses after the title.)
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4. DESCRIPTIVE NOTES (the category of the document, e.g., technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)
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5. AUTHOR(S) (Last name, first name, middle initial. If military, show rank, e.g. Burns, Maj. Frank E.)
Tikuisis, P., Belyavin, A.J., Buxton, A.C., Coleshaw, S.R.K., Higgenbottam, C., Oakley, H., Redman, P., Pasche, A., Wissler, E., Withey, R., Brooks, Capt(N) C.J.

6. DOCUMENT DATE (month and year of publication of document)	7.a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)	7.b. NO. OF REFS. (total cited in document)
August 1997	15	77

8.a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)	8.b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

9.a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)	9.b. OTHER DOCUMENT NO.(S) (any other numbers which may be assigned this document either by the originator or by the sponsor.)
DCIEM No. 97-TM-47	

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13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

The prediction of survival time for cold water immersion is very difficult due to several uncertainties. Foremost is the lack of well-documented data; hence the reliance of extrapolative techniques from controlled exposures involving mild levels of hypothermia. A second obstacle is the wide variability of individual response to cold. The challenge of prediction is further exacerbated by the ambiguity in the definition of survival time. These concerns must be addressed to improve the safety and rescue of people in the offshore environment.

An international workshop was held to investigate the role of survival prediction models with a special emphasis on terminology. Following a review of prediction methods and models, assumptions were discussed, standard definitions were agreed upon, the extension to specific populations was noted, a standard clothing menu for modeling purposes was agreed upon, the collation of case histories and their use for model calibration and validation was discussed, and future directions were summarized. The primary recommendation was the adoption of the definition of survival time as the time for a body to cool to 28°C. This definition purposely excludes the possibility of death by factors other than hypothermia such as drowning. In addition, the workshop group agreed upon a new term to signify the impairment in motor and cognitive abilities associated with a body temperature of 34°C. The time to cool to this point was termed the 'Functional' time. It can be assumed that individuals are capable of self-help up to this point. It is further recommended that this definition be applied as a threshold criterion in the design of protective garments and in the standardization of offshore safety policy.

The workshop also recognized the importance of a recent comprehensive immersion survey in the UK that provides the probability of being found alive as a function of water temperature, immersion time, and buoyancy device. This differs from the hypothermia-based models referred to above since all life-threatening possibilities are included. The value of such probabilities is the estimation of the number of survivors when large numbers of casualties are involved. It is suggested that the integration of this probability function into a body cooling model would result in a meaningful decision aid for search and rescue operators and the offshore safety community.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible, keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

water immersion, survival time, functional time, survival probability.